A Hybrid Engineering Course Combining Case-based and Lecture-based Teaching

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1. Abstract

Engineering and business school courses both aim to teach students to solve problems, but the approaches they use to reach that objective are traditionally perceived as fundamentally different. Engineering courses provide the students with dense technical knowledge that helps them give a definitive answer to a problem, while business school classes focus more on collaborative learning by confronting the students with real-world cases and by encouraging teamwork in order to find viable solutions to a question, the question not necessarily having a single black and white answer.

We combined both of these approaches in a single course by designing the semester-long course “Fundamentals of Nanobiotechnology and Nanobioscience” directed towards senior undergraduate and graduate students. It incorporated key elements of the business school case study approach to learning, without altering the class time or the elements drawn from the traditional engineering education style. The format and different active elements of this hybrid course was presented at the ASEE Annual Meeting 2018 as a work-in-progress project.

Building on that prior work, our objective here is to prove the effectiveness of the hybrid format introduced in the course. To that end, two feedback tools were implemented: (1) a pre-course survey was used to gauge the students’ self-reported knowledge on key element of the course. The same survey questions were added to the end of semester survey, thus enabling us to quantify the progress that was made. (2) Student participation was recorded during all class sessions, thus providing us with information about the effect of the business-school inspired elements on student participation, and the impacts those activities had on the traditional lecture sessions.

2. Introduction

In the past two decades, the extensive research on teaching methods has provided an increasing amount of insight in the most effective active teaching and learning processes. The outcomes of different studies vary, but a major consensus is that active learning works: at worst, active learning doesn’t harm students’ outcomes; at best, it doubles students’ retention. Consequently, active learning was incorporated in fields such as STEM, history and political sciences, and business. Each field, however, focused on different active elements: business school courses are traditionally known as mostly case-study based, while engineering courses traditionally focus more on lectures and problem-solving exercises. However, a combination of both approaches in the same course has not yet been described. We tackled this challenge in our 4000-level course “Fundamentals of Nanobiotechnology and Nanobioscience”.

To start designing the course, we needed to rely on a framework that helped in the conception of relevant, engaging, and practical classes. The “backward design” approach by Wiggins and McTighe fulfills these criteria. Instead of teaching a class by following chapters from a textbook, this method first raises the questions: “what should the students learn from this course?” and “what skills should the students acquire by the end of the semester?” By addressing these questions, the instructor can define the objectives of the course before setting any lesson plan. Then, rather than using pre-established structures for their course, they can determine the teaching elements that would be the most appropriate to reach those objectives. By continuing to move “backwards”, the topics to be emphasized can be selected, and lastly, the content of each class can be set.
Here, using backwards design, we adopt a hybrid approach, and present a multi-leveled active course. We created a new course structure that incorporates, in an engineering course, the active elements that are traditionally used in business school curricula. By doing so, the “Fundamentals of Nanobiotechnology and Nanobiology” course aims to get students more involved and engaged in the learning process, which in turns will improve both their classroom experience and their retention of the material.

3. Methods

3.1 Setting the course’s learning objectives
Using backwards design, we started by defining the learning objectives we had for the students. We targeted several levels of learning as described by Bloom’s taxonomy, which spanned from the lowest level – which consists in recalling facts and concepts – to its highest one – being able to produce a new or original idea or work in the area. At the end of the course, we wanted for the students to be:

1. Able to define nanobiotechnology in the context of modern science and engineering,
2. Capable of understanding and interpreting concepts such as intermolecular bonds, adsorption and binding/unbinding processes, nanoscale transport mechanisms, and degradation mechanisms at the nanoscale,
3. Comfortable in estimating orders of magnitude of objects that relate to engineering,
4. Capable of comparing and evaluating research papers related to nanobiotechnology with a critical mind,
5. Able to take a position towards an engineering-related question and defend their position in front of others,
6. Able to describe examples of applications and outline the state of the art in nanobiotechnology,
7. Able to contribute to and build upon team ideas through discussion.

3.2 Designing the course
Once the learning objectives were set, the structure of the class was considered as a means to reach these objectives. Relying on the positive effects of active learning, we designed a novel course format in which the class-time was divided around three different types of activities that succeeded each other using the pattern presented in Figure 1. The topic of each unit reflected a key area that we aimed to investigate in the course, and we focused on topics that are both more favorable to generate longer class discussions, and who have been the researched in the past. Examples of such topics include: “Nanobiotechnology and its applications”, “Lifetime of nanobiodevices” or “Reproducing macroscale bonds at the nanoscale”.

Figure 1. Basic unit of the course. Each “cycle” focuses on one key topic related to nanobiotechnology. It consists of one or two lectures on a topic, followed by a case study and two case histories – adding up to a total of four or five sessions dedicated to this topic. The course was composed of five cycles of the type.

3.2.1. Lectures

Lectures were the most traditional elements of engineering teaching that were implemented in this course. They made up less than half of the overall class time, and they provided the students with enough background material to be able to address the questions that were raised in the following case study and case histories. Lectures, however, were not passive.

First, lectures were partially “flipped”: the foundational material of each lecture series was recorded and divided into one or several short videos. The students had to watch the videos in preparation for the class. To ensure their engagement in this process, they had to take a short online quiz on each lecture video after watching it. These short quizzes emphasized the main take-away points of the online lecture and ensured student participation. Once in class, the instructor drew the students’ attention on the main take-home messages of the flipped lecture, and the students had the opportunity to ask for clarifications.

Furthermore, flipped lectures opened up time for making the in-class lectures more active. All lectures incorporated elements for active learning such as think-pair-share exercises or small group discussions, the overarching aim being to bring the students not only to a higher level of understanding, but also to teach them to develop, formulate and justify their ideas.

3.2.2. Case Studies

Collaborative learning improves learning outcomes in a broad range of aspects from academic achievement to students’ retention of the material. Collaborative learning was introduced in this course through the use of business-school inspired classes. In groups of 3 or 4, students had to think about research questions related to the previous lectures’ material. The basic structure of case study classes (Figure 2) would be repeated 3 or 4 times during the 75-minute class. All questions were broad and open-ended, but got gradually more specific and thought-provoking. For instance, the first question was often about the most interesting research direction to follow knowing the material that was taught in the previous lecture. The next question consisted in investigating the feasibility or the implementation of the research ideas the groups came up with; and the next question would go in a more in-depth analysis of the economical or societal pay-off
of that research. For instance, the questions that were asked during the “Reproducing macroscale bonds at the nanoscale” were:

1. What are the different mechanisms that are used at the macroscale to create a bond? Name and describe as many of them as you can.
2. What are some nanoscale bonding mechanisms? To what macroscale mechanism(s) are they similar?
3. If you had to reproduce a macroscale bond (that you haven’t cited in the previous question) at the nanoscale, which one would it be and how would you do it?

Figure 2. Pattern of a case study session. This pattern was repeated three or four times per case study, depending on the difficulty of the questions and the students’ participation.

Meanwhile, the instructor circulated between the groups, aligned the students’ perspectives towards the learning objectives of the session, and generated longer class discussions. These classes exclusively consisted of discussions about the empirical applications of the material, so they automatically turned the classroom into a more interactive and active environment in which the material was taught in a more personalized way.

Furthermore, the first case study, entitled “What are the future prospects in nanobiotechnology?” was repeated as the last case study of the course. We recorded the responses given by the different groups the first time they were presented with the topics, and presented the students with their own answers the second time. Thus, through the critique of their own answers, the students were able to gauge their own progress.

3.2.3. Case histories

The case histories consisted in the reading, understanding and critiquing of papers that could be considered as responses to the previous case study. They presented what research has been done in relation to the preceding lecture material and case study. By showing how the course’s material is currently used and looked upon by researchers, the case histories were intended to give the students an idea of all the different ramifications of the field of nanobiotechnology. Thus, the case histories served as conclusions to the three or four classes spent on a specific subject. Typical questions that were asked during case history sessions include:

1. What was the state-of-the-art in the field before this paper was published?
2. Why is the research presented in this paper relevant to nanobiotechnology?
3. Critique the paper: if you had to write it, what would you keep, and what would you do differently?
In a few cases, we also interviewed the first author of a case history paper. The interviews addressed two major topics: the paper itself, and the author’s professional career. First, the history behind the scientific article was investigated through questions about the time it took to get results, the publishing process, the easiest or hardest part of the experiments, etc. Then, to expose students to different career paths that exist in nanobiotechnology, the authors were questioned about their career and its evolution since they finished their graduate studies.

Thanks to this course format, the students were active in learning the course material before, during and after the time allocated to the class (Table 1).

<table>
<thead>
<tr>
<th>Before the class</th>
<th>During the class</th>
<th>After the class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lectures</td>
<td>Watch lecture videos</td>
<td>Participate in discussions</td>
</tr>
<tr>
<td></td>
<td>Answer to online quizzes</td>
<td>Ask for clarifications</td>
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<td></td>
<td></td>
<td>Defend one’s ideas</td>
</tr>
<tr>
<td>Case studies</td>
<td>Review lecture material</td>
<td>Participate in discussions</td>
</tr>
<tr>
<td></td>
<td>Do homework</td>
<td>Work on the case with one’s team</td>
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<tr>
<td></td>
<td></td>
<td>Present one’s team’s answers to the questions</td>
</tr>
<tr>
<td>Case histories</td>
<td>Review lecture material</td>
<td>Participate in discussions</td>
</tr>
<tr>
<td></td>
<td>Review case study</td>
<td>Be active in group activities</td>
</tr>
<tr>
<td></td>
<td>Read case history paper</td>
<td>Critique the paper</td>
</tr>
</tbody>
</table>

Table 1. Students’ involvement in the course throughout a course “unit”.

3.2.4 Design of the classes

Once the format of the course was defined, each class was conceived with the aim of addressing one or more of the previously cited learning objectives. Suitable examples and activities were determined and incorporated in them.

3.3 Teaching the class

The course “Fundamentals of Nanobiotechnology and Nanobioscience” has been taught in as an integral part of the semester course schedule in the School of Engineering and Applied Sciences of Columbia University since Spring 2017. It is intended for senior undergraduate students as well as graduate students. The class consists of 28 75-minute long lectures, as well as a 3-hour long final. In Spring 2017, 7 students enrolled in the course, 17 students enrolled in Spring 2018, and in Spring 2019, this number rose to 27 students. The students were from different academic backgrounds: they majored in fields such as Biomedical engineering, Biotechnology, and Mechanical Engineering.

3.4 Assessment of the course

3.4.1 Quizzes

The online quizzes that accompanied the flipped lectures acted as a continuous formative assessment tool for the instructors. By analyzing the outcome of the quizzes before the beginning of the next class, the instructors were able to implement methods of Just-in-Time Teaching (JiTT)
by adjusting the material to the students' needs. For instance, if a specific concept was misunderstood by the students, the instructors became aware of it thanks to the quizzes. As a result, they would dedicate a few minutes of the next class to explain that concept and/or add details about it in the lecture video that would be used in the following years.

To encourage the students to engage with the material, 10% of the course's grade was contingent upon their taking the quizzes.

3.4.2 Homework
Homework sets were intermediaries between summative and formative assessments. Five homework sets were designed using backwards design. Each set addressed at least two of the learning objectives of the course, and a special emphasis was put on the course’s third learning objective (i.e. being comfortable in estimating orders of magnitude of objects that relate to engineering). Each assignment grade accounted for 20% of the total homework grade, and the average score of the homework sets counted for 40% of the course grade.

3.4.3 Final
The final exam of the course was the most prominent summative assessment of the students’ learning. Once again, each question was designed by referring to the learning objectives of the course. The final exam was 3 hours long, closed book, and tested the students’ knowledge of the key concepts addressed in the course. It accounted for 50% of the course grade.

3.5 Assessment of the active elements

3.5.1 Pre-course and end of course surveys
The validity and reliability of self-reported data has been discussed for nearly half a century. Now, researchers generally agree that self-reported estimates of learning are valid, without necessarily being a substitute for objective measures. For instance, Anaya et. al determined that GPA, student-reported growth, and scores on the GRE are all three valid measures of learning. Relying on these findings, we designed two optional and anonymous surveys, one of which was taken during the first week of the semester (this survey will later on be referred to as the pre-course survey), and the other one was an end of course survey. The students’ self-reported responses were then analyzed in order to assess the effectiveness of the implemented active measures.

The pre-course survey consisted of two questions aimed at gauging the students’ knowledge on both the material that would be taught in the course, and the non-topic-specific learning objectives of the course. The post-course survey consisted of the same questions as the pre-course survey, and also included (a) an additional multiple-choice question regarding the progression of the course and (b) four open-ended questions about the different active components of the course, as well as an evaluation of overall strengths and weaknesses of the course.

3.5.2 Student participation
Each student’s participation was evaluated throughout the semester. This evaluation, which started after the drop period for the semester ended (for consistency), recorded the number of times each student participated in the class, whether by asking a question, expressing an idea, or reporting a group’s response to an in-class exercise. One-word answers – such as “yes” or “no” – or non-
course specific question – such as asking to rewrite a word on the board for readability purposes – were not taken into account.

4. Results

4.1 End of course survey

Results from the end of course surveys are presented in Figures 3 and 4. The end of course survey was completed by 7 out of 7 students in Spring 2017, and by 10 out of 17 students in Spring 2018. The survey questions and course content having remained the same for both semesters, the cumulative results from both semesters are presented here.

![Bar chart showing student self-evaluation](image)

**Figure 3.** Students’ end of course self-evaluation of the extent to which the learning objectives of the course had been met. The x-axis represents the percentage of students falling within each category.
Figure 4. Students’ end of course evaluation of the active tools used during the course. The x-axis represents the percentage of students falling within each category.

4.2 Comparison of pre- and post-course survey data

Pre-course survey results were collected in Spring 2018, and 14 out of 17 students responded to it, while 10 out of 17 students responded to the end of course survey. The histograms presented in Figure 5 are derived from the comparison of the pre-course survey and the end of course survey responses regarding the course’s learning objectives. As of the questions addressed in Figure 6, they assess the broader impact the course had on teaching students to think both scientifically and critically.
(a) I am able to define nanobiotechnology in the context of modern science and engineering

- Strongly Agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

(b) I am able to describe examples of applications and outline the state-of-the-art in nanobiotechnology

- Strongly Agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree
Figure 5. Comparison of the pre-course and end of course survey. The x-axis represents the percentage of students falling within each category. (a) The question asked is a rephrased version of the first learning objective of the course. This learning objective tackles the lowest level of Bloom’s taxonomy, recalling facts and basic concepts. (b) The question asked is a rephrased version of the sixth learning objective of the course. This learning objective tackles the second lowest level of Bloom’s taxonomy, explaining and describing ideas and concepts. (c) The question asked is a rephrased version of the third learning objective of the course. This learning objective tackles the second highest level of Bloom’s taxonomy, evaluating and justifying a stand or a decision. (d) The question asked here is a rephrased version of the seventh learning objective of
the course. This learning objective tackles the highest level of Bloom’s taxonomy, designing new or original works and responses.
4.2 Written Feedback

At the end of the end of course survey, students had the option to express their opinion on the course’s strengths and weaknesses. All the students who took the survey also seized this opportunity to give feedback on the course.

Figure 6. Comparison of the pre-course and end of course survey. The x-axis represents the percentage of students falling within each category.
Representative student comments are reproduced below.

**About the course in general:**

*Overall, this was my favorite class this semester, I very much enjoyed the homework assignments that elicited both a creative thought process and problem-solving skills.*

*Wonderful class and instruction. Course made me think critically and made me feel like I was learning things in a purposeful way, rather than just for the sake of learning.*

*Makes you think about problems conceptually and deeply in order to allow students a fuller understanding. Course structured in a way that allows knowledge to be built upon class after class.*

*I truly enjoyed this class and learned so much from it.*

**About the biggest strength of the course:**

*Course structure, online assignments and resources, lecture style that encourages student engagement.*

*I would have kept the number and format/style of homework and quizzes the same.*

*I liked the in-class lectures they were solid.*

*I would not have changed a thing.*

**About possible improvements to the course:**

*I personally would have been interested in learning a few more applications of nanobiotechnology in medicine.*

*It might have been nice if the case histories emphasized a broader range of topics in nanobiotechnology than motor proteins.*

*Solidify notes and have them posted after the lecture.*

*I would have tried to keep students updated with materials from the lectures by posting notes online. Also, I would have tried to communicate more with students in terms of the progress of the course (as in reminding what is due when, for example) through email.*

*Maybe set reminders for coursework to email?*

*A lot of ideation came from the classroom, but was unsure if we covered every possible or major idea that was related to a topic (I'm assuming we did) but starting us off in appropriate directions would have maybe been more interesting to prompt discussion.*

**About flipped lectures:**

*Thoroughly enjoyed them.*
I am personally a big fan of the flipped lecture style and thought it helped with my comprehension of the papers we read in advance.

Flipped lectures are great but it wasn't always timed or content matched exactly.

Keep doing them.

About case stories and case histories:
While it was definitely something we discussed in nearly every case study, I think addressing the "state of the art" at the time of each paper's publishing is especially important to provide context and emphasize progress.

I like the case studies yes. It would be nice if this class was taught in a more collaborative classroom that facilitates more meaningful conversations.

I thought that case histories are insightful and I liked how you always placed case histories after case studies, since case study portrays a problem and case history describes a solution. It was fun to see what the scientists actually came up with as solutions to the problems.

A potentially good application of all the case studies would have been a final project oriented around theoretically designing something that build off all the material rather than just an exam.

Perhaps providing the class with some preparatory questions or topics to research could be beneficial and move things along even more during the short class times.

[They] helped better understand underlying concepts.

More specifically, students wrote about the last case study of the course:

I think reviewing the discussions from the very beginning of the semester regarding the potential applications of the nanopropeller was a valuable exercise. Distinguishing the lofty, long-term goals of nanotechnology from the accomplishments of individual papers is an important way to illustrate the difference between 'goal' and 'objective'.

It showed how much we learned and that was cool.

I have a more realistic and thoughtful process of evaluation when reading it the second time around.

Yes, it was informative to discuss the same case study with a more extensive understanding of the current "state of the art" in nanobiotechnology.

I think this is just to complete the circle. By coming back to what you started out with at the end, you can see how everything ties in with each other in the course.
4.3 Student participation

The student-specific and class-specific participation data for Spring 2018 is represented in Figures 7 and 8. The average student participation in the different types of classes (lectures, case studies, and case histories) is shown in Figure 9.

**Figure 7.** Students’ active participation at the end of the semester. Each number on the x-axis represents a student.
Figure 8. Average number of interventions per student in each class. There is no data for the period between March 12th and March 16th due to spring break. Due to high variations between individual students’ participation, error bars have not been added to this graph.

Figure 9. Average number of interventions per student and per class. The error bars represent the standard error of the mean. Student t-tests show that the difference between participation in
lectures and the other two types of classes is statistically significant at the 5% level, whereas the
difference between the case studies and the case histories is not statistically significant.

5. Discussion

5.1 Survey data

By getting students more involved and engaged in the learning process, we aimed to address a
broader range of learning objectives, and the students believe that all learning objectives have been
met (Figure 3). They consider that the course structure encourages active learning and gives a more
applied perspective on engineering; for them, the active elements were useful, and they got more
comfortable answering the broad case study questions as the semester went on (Figure 4).

Figure 5 highlights the fact that the students feel that they progressed in the acquisition of the
set of skills that the learning objectives were aiming at, no matter what level in Bloom’s taxonomy
these skills were referring back to. This is all the more relevant for objectives that tackle the higher
levels of learning since they do not only concern nanobiotechnology per se: they rather concern
engineering in a more general sense and their goal is to teach students to have the proper mindset
when confronted with engineering-related problems. This is corroborated by the results presented
in Figure 6: even though this course was not a Journal Club, students were more comfortable in
reading, understanding and critiquing a journal publication at the end of the semester.

5.2 Student feedback

The students written feedback informs us that overall, the students appreciated the structure of
the course as well as its assessment methods. They enjoyed the course and were aware of their
own progress. When asked about the possible improvements that can be made to the course, three
themes were recurrent:
1. Being sent email reminders concerning the coursework deadlines,
2. In addition to lecture videos, posting the lecture notes online, and
3. Being presented with a broader range of applications.
This feedback is very valuable, since it generates a positive feedback loop that will help to improve
the course at each one of its iterations.

5.3 Student participation

The student-specific participation data (Figure 7) helps visualize the types of classroom
behavior students have: about one half of the students are overall less inclined to participate in in-
class discussion (data points 1 to 8), while we can observe an increasing range of participation for
the other half of the students (data points 9 to 17). Even though we can consider the second half
of student as active and engaged with the course material, these results do not imply that the less
participative students were not engaged in the course: the observed differences in student
participation can be attributed to a number of factors, including the students’ personalities, their
background and their interest in the course.

As expected, students were more active in case study and case history classes (Figure 9). It is
also interesting to note that, excluding the participation on the March 8th class, the students’
participation is U-shaped (Fig. 8): the participation is high at the beginning and the end of the
semester, and is at its lowest mid-semester. This can be a reflection of students’ motivation and/or
morale, which can in itself be the subject of future investigations.
6. Conclusion
The “Fundamentals of Nanobiotechnology and Nanobioscience” course is now a well-established course in Columbia University’s Biomedical Engineering department. While the obtained results are positive and encouraging, we aim to continue to improve the course in the future by taking the students’ feedback into account. For instance, we are posting the lecture notes online and addressing a broader range of application in the 2019 iteration of the course. Furthermore, we hope to apply this structure to other courses in biomedical engineering, thus enhancing the students’ experience, their active interaction with the material, and as a result, their learning.

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